

SILICON DENDRITIC WEB GROWTH THERMAL ANALYSIS TASK

JET PROPULSION LABORATORY

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Objectives

- o ESTABLISH THE PERTINENT THERMAL ASPECTS OF SILICON DENDRITIC WEB GROWTH
- o EVALUATE THE PRESENT SILICON DENDRITIC WEB GROWTH SYSTEM
- o PROVIDE THERMAL DESIGN INPUTS FOR THE SILICON WEB GROWTH STRESS MINIMIZATION TASK
- o GENERATE THERMAL DESIGN GUIDES FOR AN ADVANCED SILICON WEB GROWTH SYSTEM

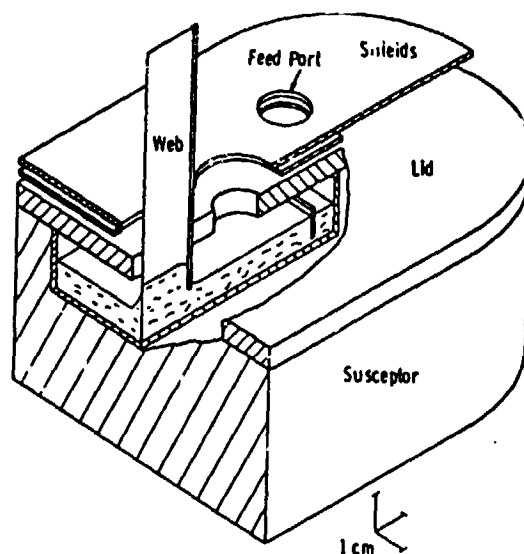
Silicon Dendritic Web Growth

- o BASIC CONCEPTS : DESIGN AND OPERATING PARAMETERS
- o THERMAL MODELING OF SUSCEPTOR - CRUCIBLE - SILICON SYSTEM
- o SOURCE OF THERMAL CONVECTION CURRENTS AND THEIR SUPPRESSION
- o THERMAL ANALYSIS OF SILICON DENDRITIC WEB GROWTH SYSTEM
- o THERMAL STACK : ANALYSIS AND DESIGN
- o COLD SHOE : ANALYSIS AND DESIGN

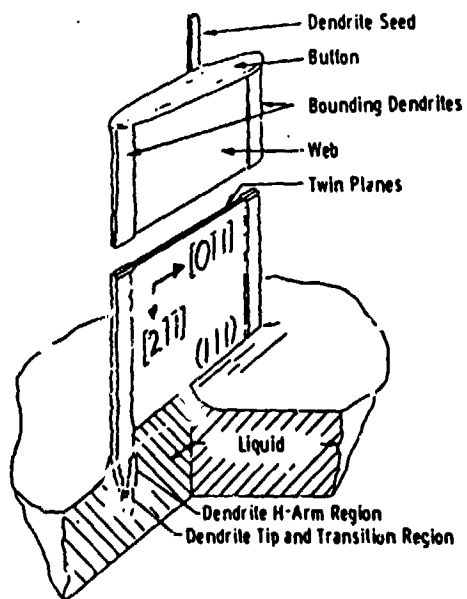


Basic Concepts:
Design and Operating Parameters

Growth Procedure (Westinghouse Concepts)

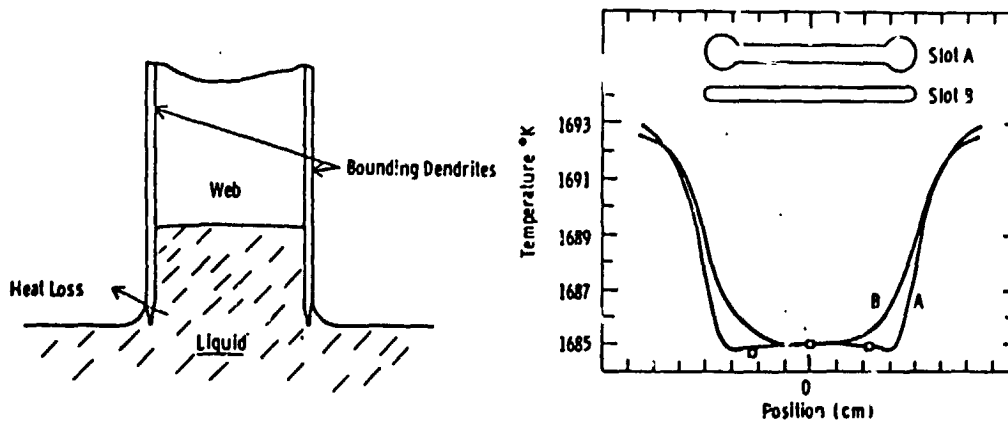


HOT ZONE - SECTIONAL VIEW (REFERENCE 1)



SILICON WEB GROWTH (REFERENCE 1)

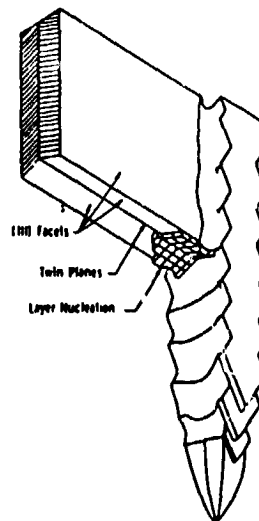
Thermal Factors (Westinghouse Concepts)



TEMPERATURE PROFILE AS A FUNCTION OF SLOT GEOMETRY (REFERENCE 1)

- CONDITION FOR GROWTH: FLAT TEMPERATURE PROFILE UNDER THE GROWTH INTERFACE AND POSITIVE TEMPERATURE GRADIENT IN REGIONS AWAY FROM THE GROWTH INTERFACE.

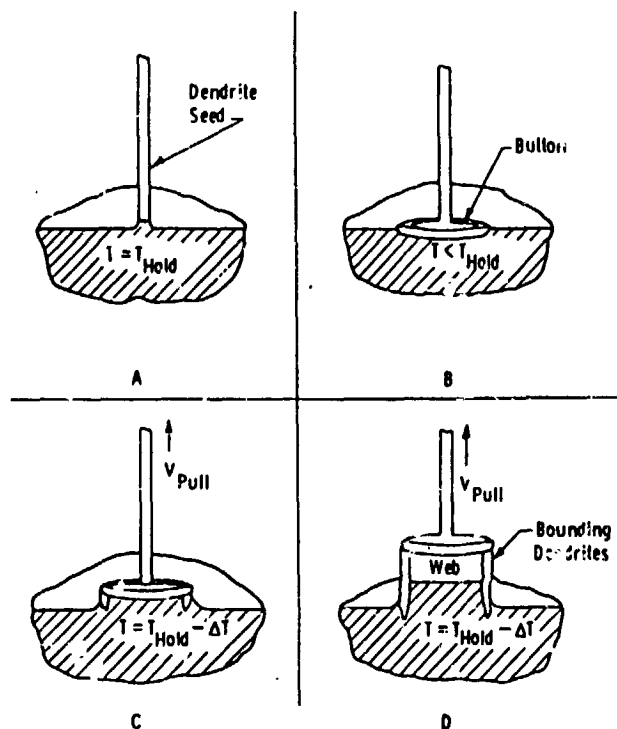
Growth Procedure



GROWTH FRONT (INTERFACE)

- STABILITY OF LIQUID-SOLID INTERFACE IS KEY TO STABLE GROWTH (REFERENCE 1)

Web Growth Initiation (Westinghouse Concepts)

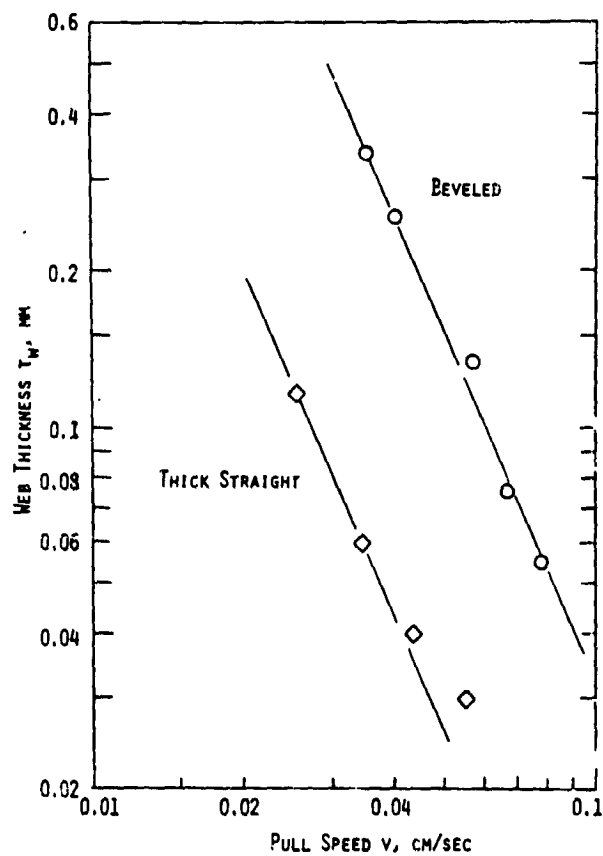
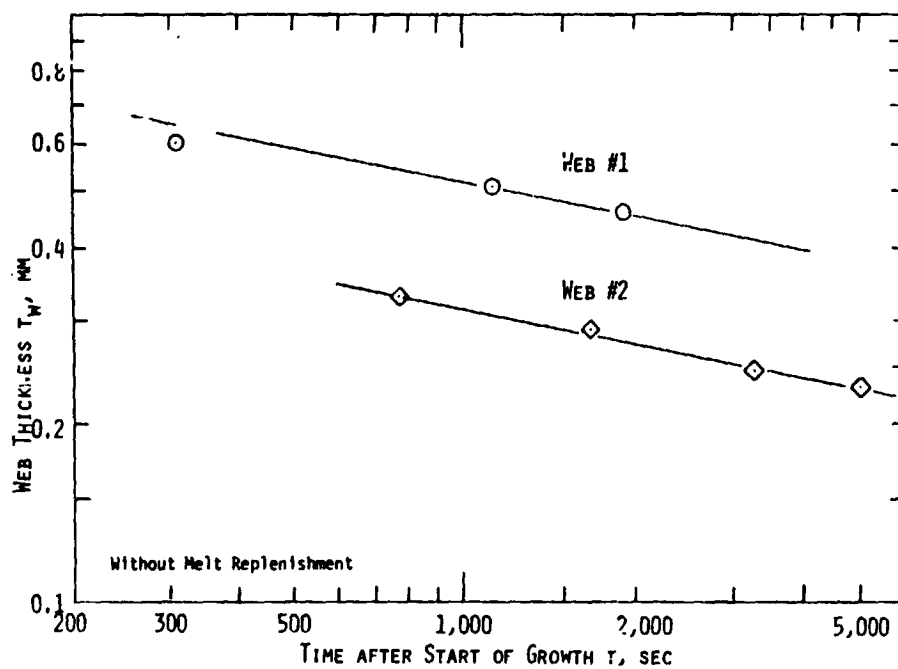


SEEDING AND WEB PULLING (REFERENCE 1)

System Configured for:

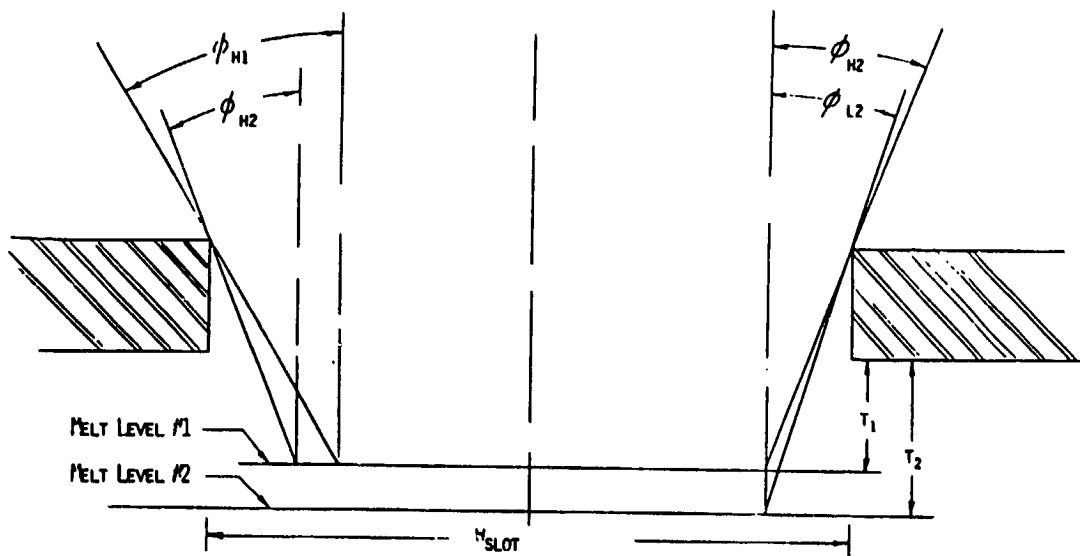
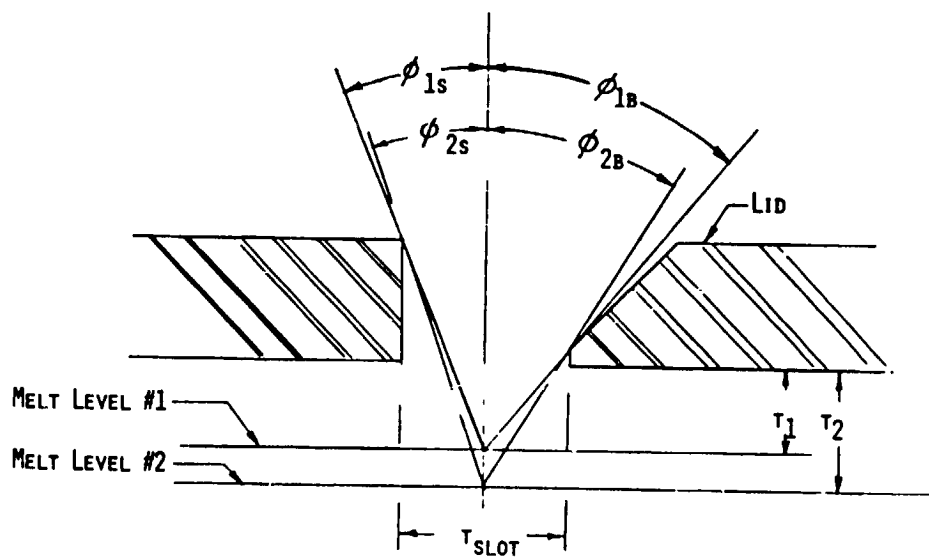
- o GROWTH OF A BUTTON
- o GROWTH OF DENDRITIC WEB
- o CONTROLLED COOLING OF DENDRITIC WEB

Web Growth Correlations
(Derived from Data of Reference 2)

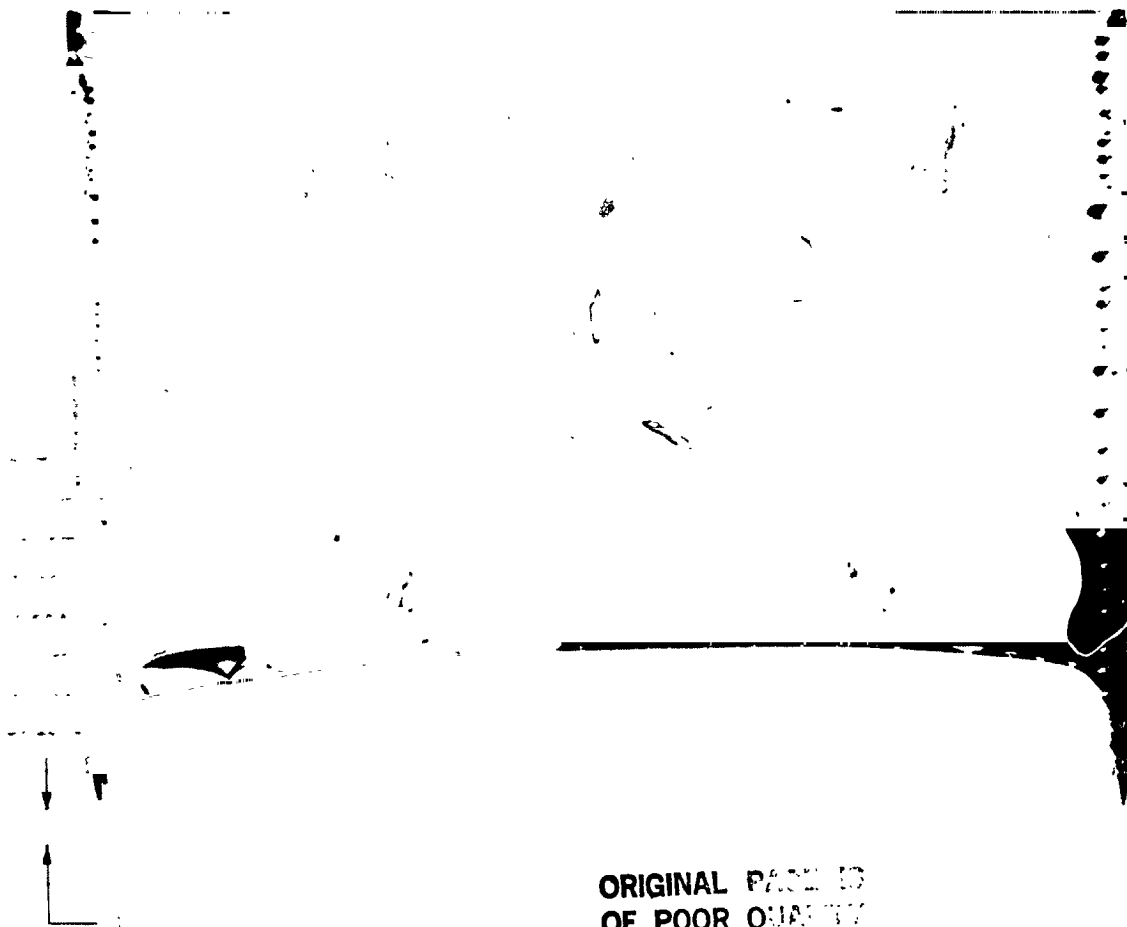


Parameters Affecting Web Growth Rate

- o MELT TEMPERATURE
- o VIEW FACTOR (COOLING RATE)
 1. MELT-LID GAP
 2. SLOT WIDTH
 3. SLOT CONFIGURATION
- o PULL SPEED



Tail of Silicon Web After Hot Pullout

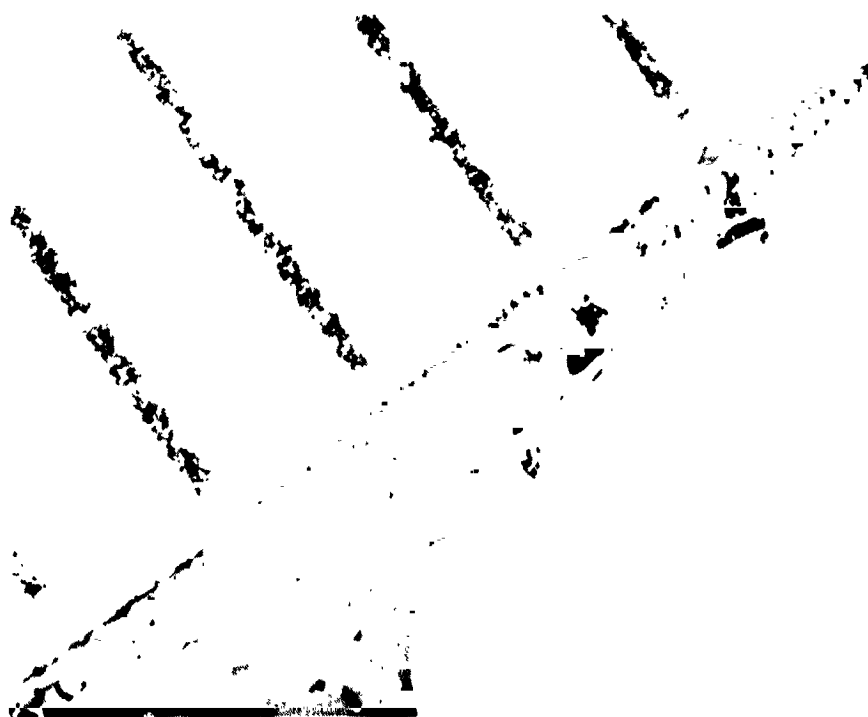


Left Side of Silicon Web

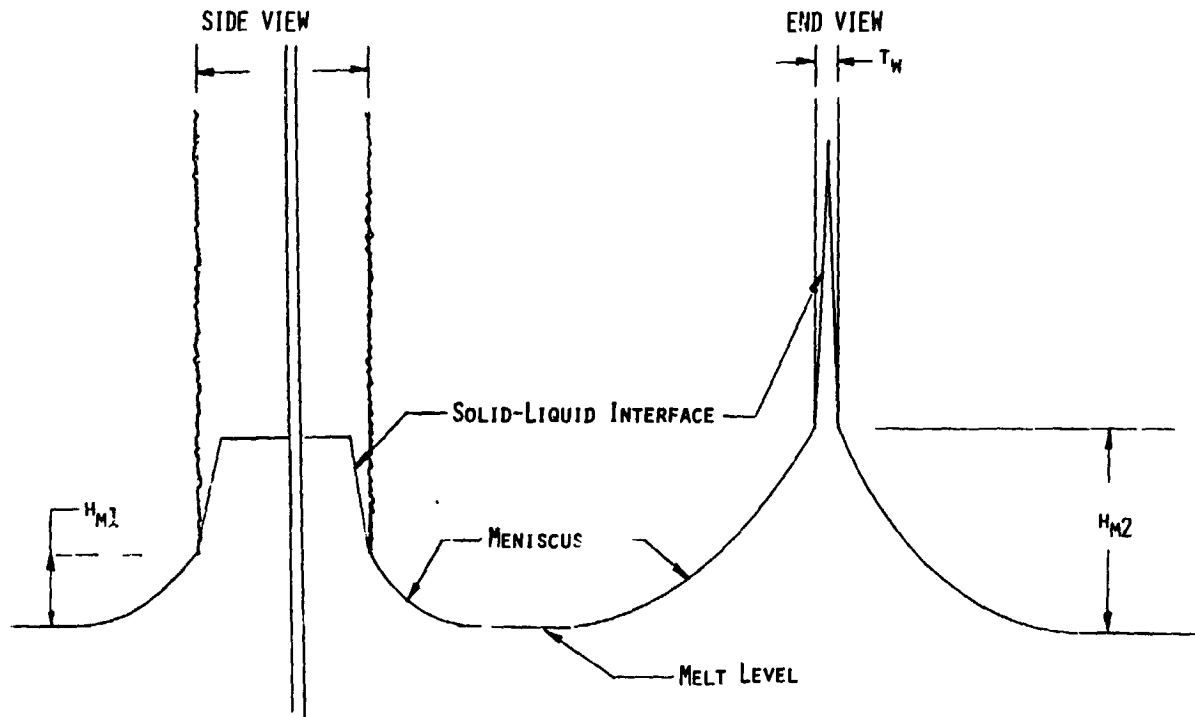
ORIGINAL SILICON
OF POOR QUALITY



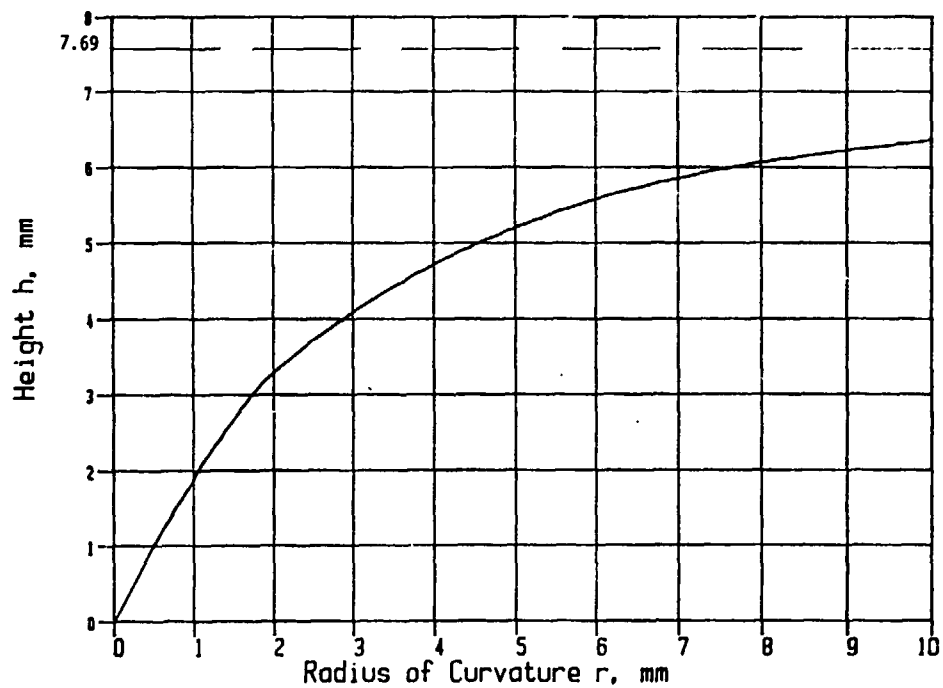
Right Side of Web



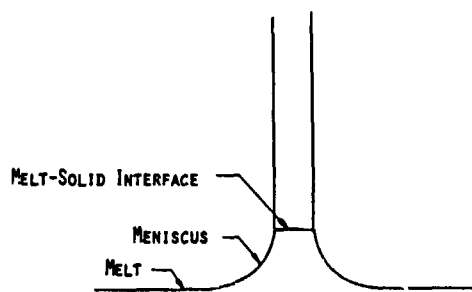
Apparent Configuration During Growth



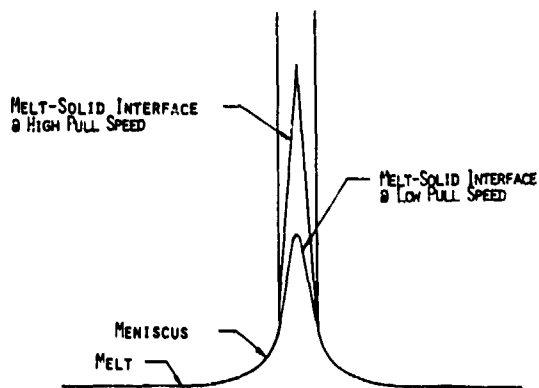
Meniscus Height at Zero Degree



Melt-Solid Interface

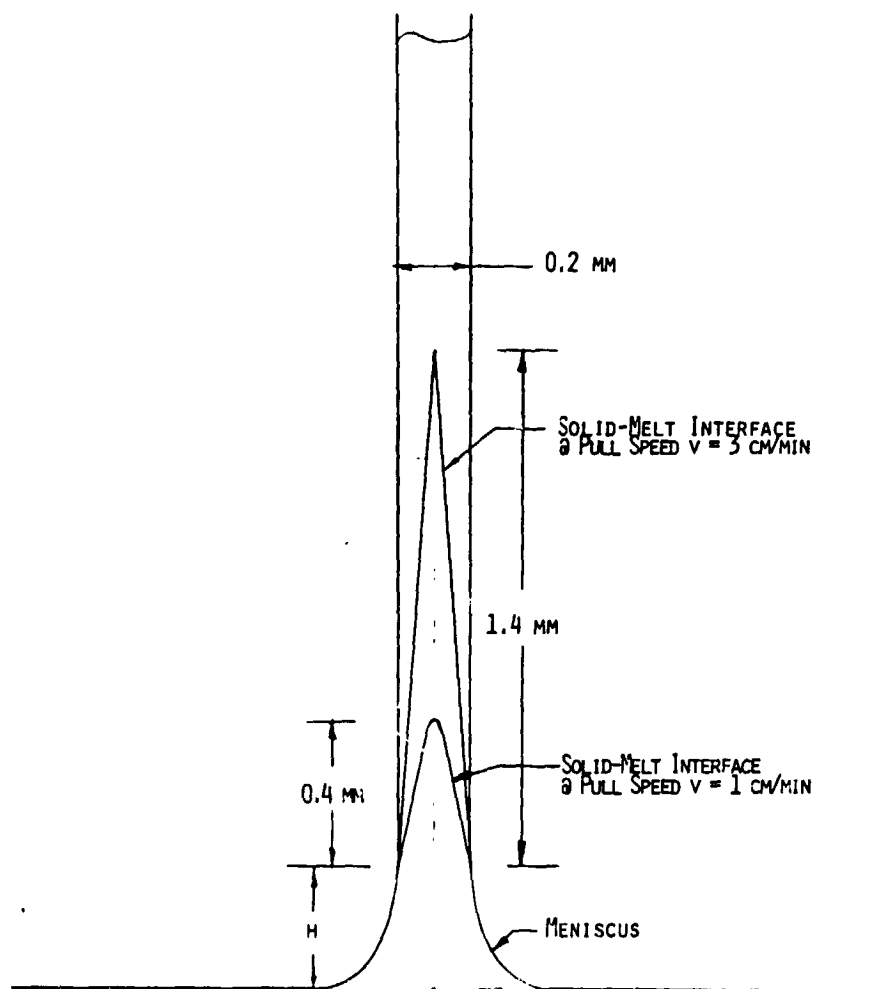


CONCEPT #1

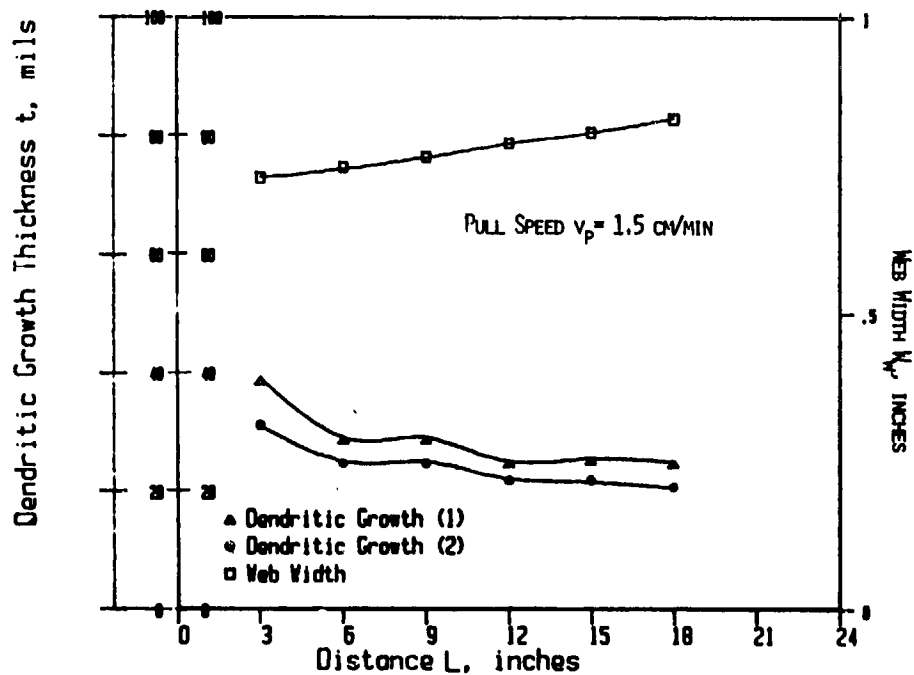
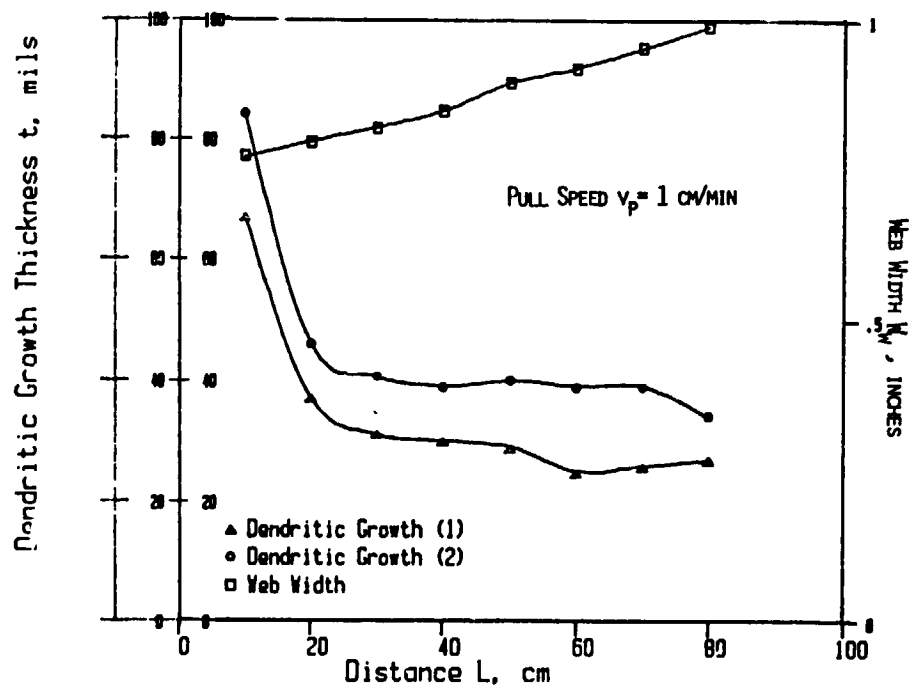


CONCEPT #2

Melt-Solid Interface

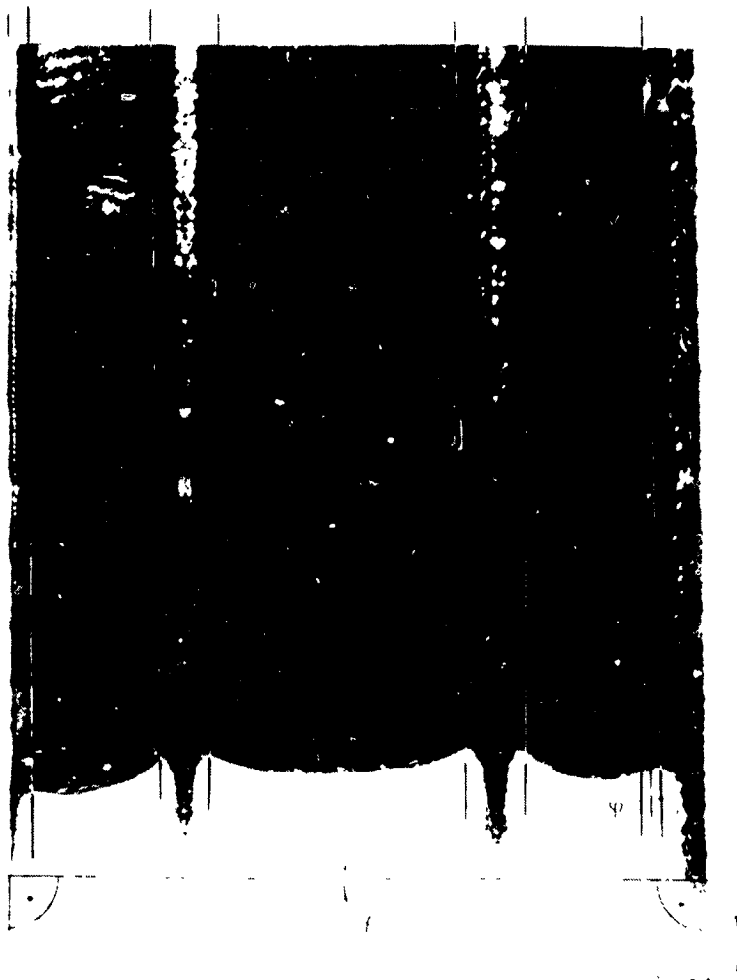


Web Width and Dendritic Growth (Westinghouse Lid)



Web Growth Phenomena

ORIGINAL PAGE IS
OF POOR QUALITY



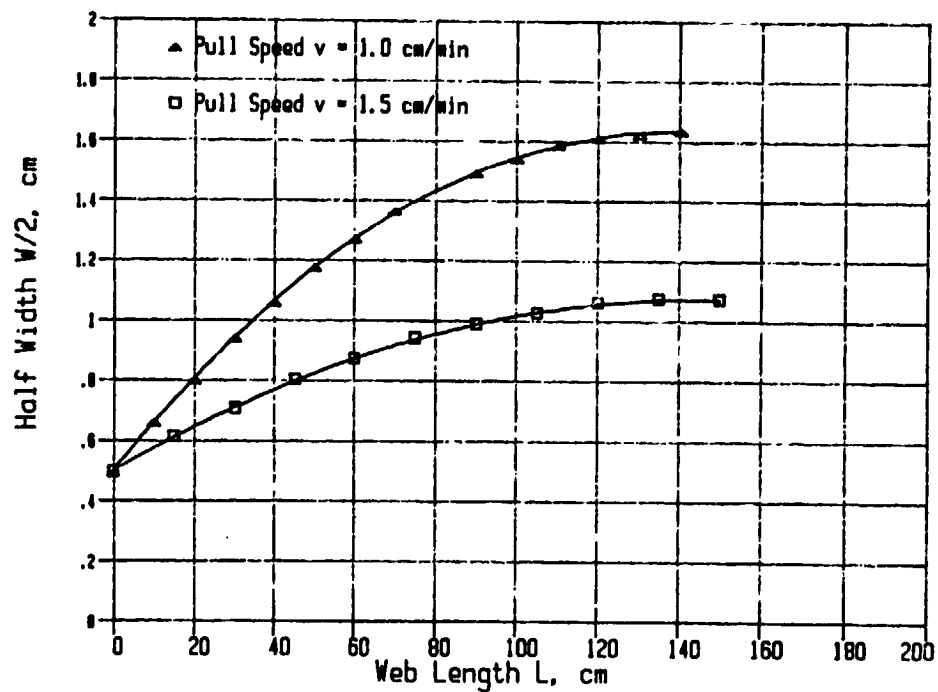
Web Growth Relationship

$$\left\{ (DX/DL)^2 + R^2 \right\}^{1/2} v = \left[z F(x) \epsilon \sigma T_m^4 - k \Delta T / H_m \right] / \left[\rho (\Delta H + c_p \Delta T) \right]$$

$$\left\{ (DX/DT)^2 + (vR)^2 \right\}^{1/2} =$$

$$\Delta T = T - T_m$$

Predicted Silicon Web Growth (Westinghouse Lid Configuration)

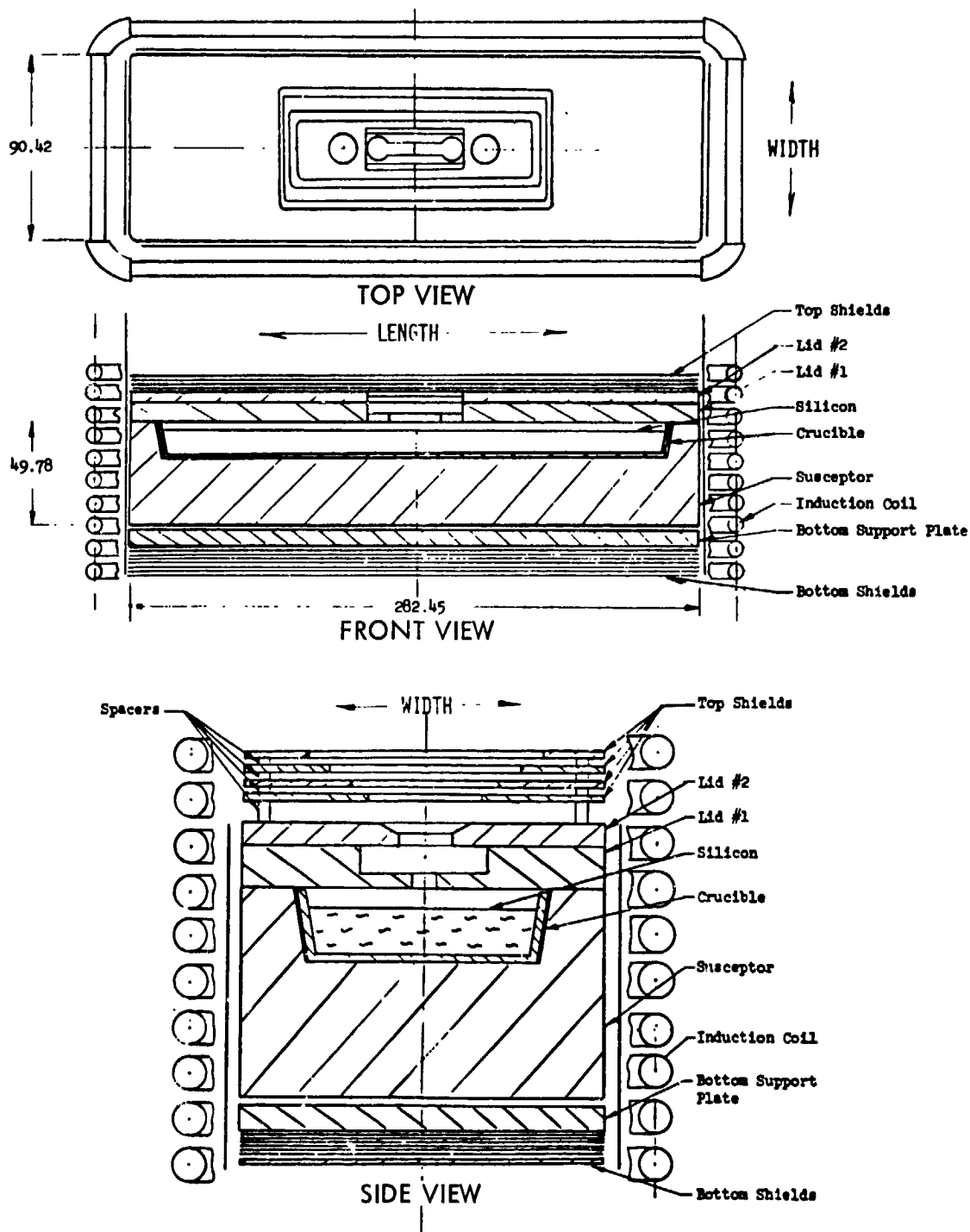


Growth Parameters

- o PULL SPEED
- o VIEW FACTOR
 - A. MELT LEVEL
 - B. WEB POSITION
- o MELT TEMPERATURE
 - A. MELT STABILITY
 - B. TEMPERATURE CONTROL

Thermal Modeling
of
Susceptor/Crucible/Silicon System

Silicon Web Growth System
(As Delivered by Westinghouse)



SILICON MATERIAL AND JPL WEB TEAM

Material Properties

SILICON @ Melting Temperature

Heat of Fusion	1.80x10 ⁶ J/kg (11)
Melting Temperature	1685 ±2K (1)
	<u>Solid</u> <u>Liquid</u>
Density	2288 kg/m ³ (1) 2540 Kg/m ³ (1)
Specific Heat	1036 J/kg-K (1) 1008 J/kg-K (1)
Thermal Conductivity	23.0 W/m-K (1) 67 W/m-K (1)
	14 W/m-K (estimated)
Kinematic Viscosity	36.36X10 ⁻⁸ m ² /s (1)
Surface Tension	0.736 N/m (1)
Volume Expansivity	1.49X10 ⁻⁴ 1/K (1)
Emissivity	0.46 (2,12) 0.64 (3)

MOLYBDENUM @ 1700K

Density (@ 20°C)	10300 kg/m ³ (13)
Specific Heat	335 J/kg-K (8)
Thermal Conductivity	97 W/m-K (5)
Coefficient of Expansion (linear) (@ 20°C)	5.4X10 ⁻⁶ 1/K (13)
Emissivity (polished surfaces, non-oxidized)	0.2 (9)
Emissivity(machined surfaces, oxidized)	0.8 (9)

ARGON

Thermal Conductivity	1700K 0.0615 W/m-K (7)
	1200K 0.0481 W/m-K
	700K 0.0336 W/m-K

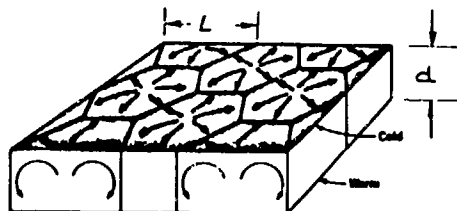
$$k = 3.87259 \times 10^{-4} T^{0.68129} \text{ W/m-K}$$

FUSED QUARTZ @ 1700K

Density	2.2 grams/cm ³ (4)
Specific Heat	0.7535 J/gram-K (4)
Thermal Conductivity	2.0 W/m-K (6)
Coefficient of Expansion (linear)	5.6X10 ⁻⁷ 1/K (4)
Total Transmission (2 mm thickness)	0.68 (10)
Softening Point (approximately)	1938 K (4)

Source of Thermal Convection Currents and
Suppression of Thermal Instabilities

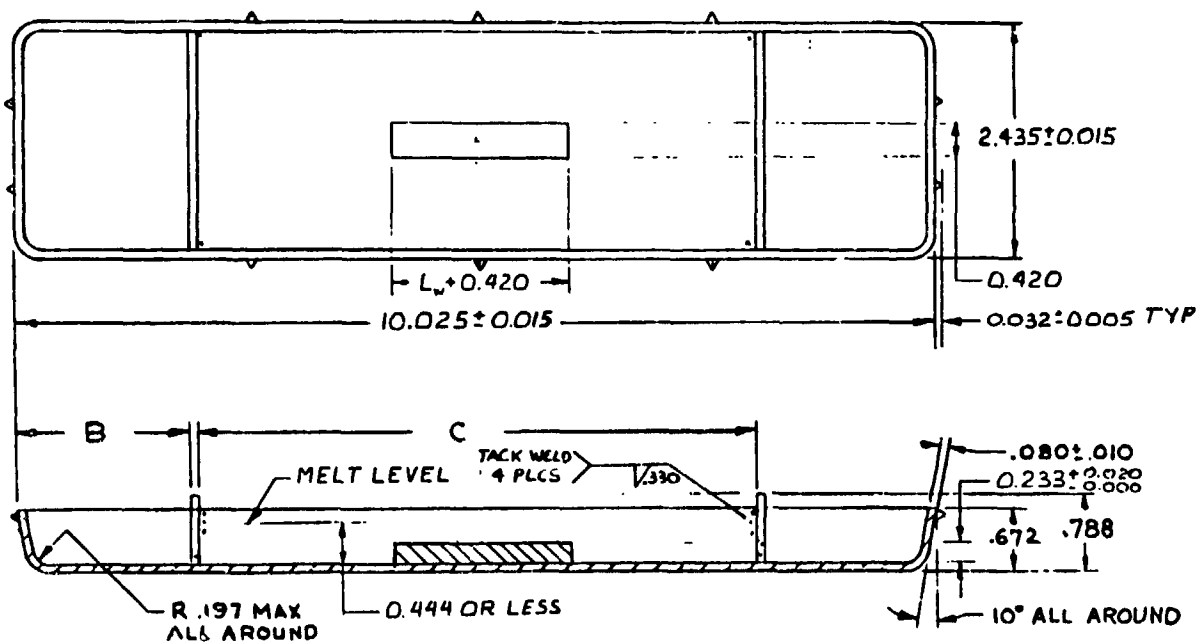
Thermal Convection in Silicon Melt



BENARD CELL STRUCTURE

$$d_{cr} = [C_{cr} / (\rho g \beta / \mu \alpha \nu)]^{1/4}$$

Suggested Crucible Design

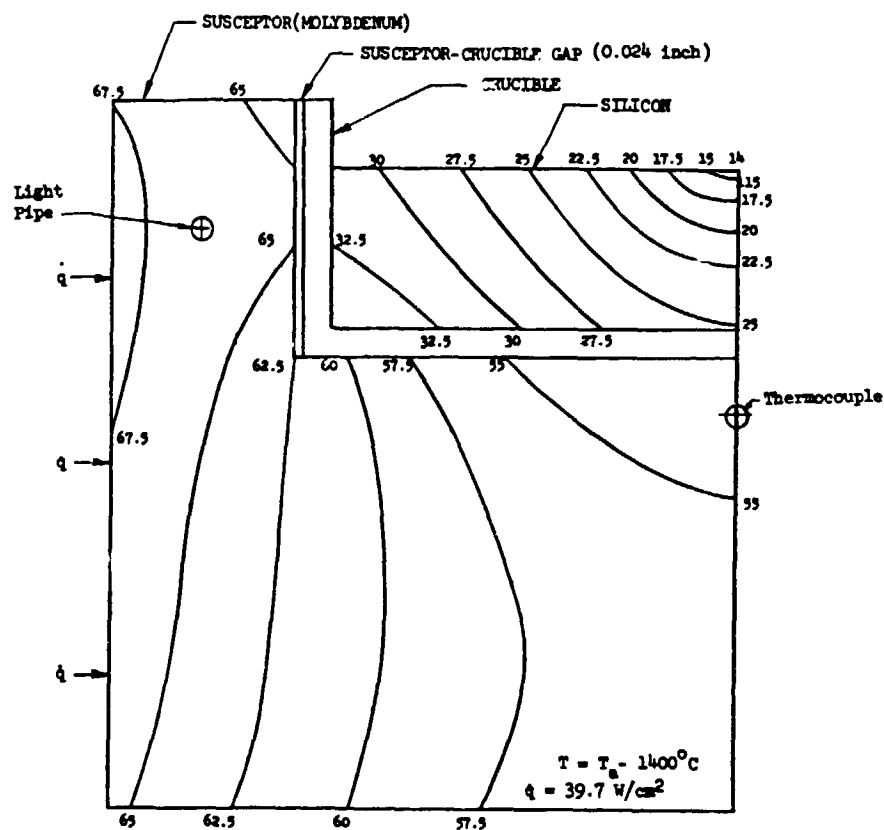


REFERENCE: DRAWING 390 DRAOR

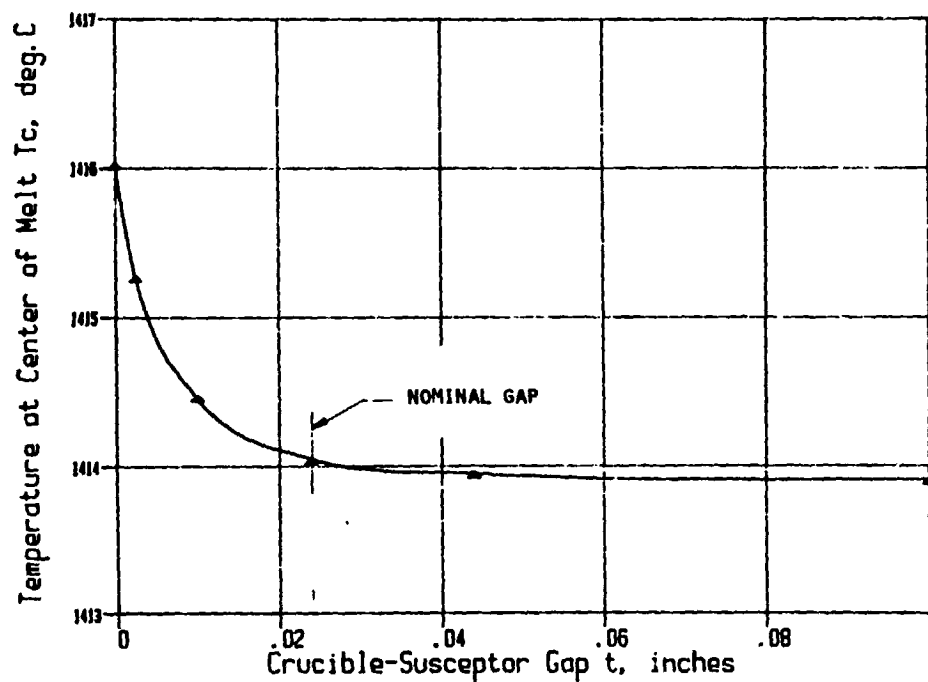
Thermal Analysis of Silicon Dendritic Web
Growth System: Present and Future

SILICON MATERIAL AND JPL WEB TEAM

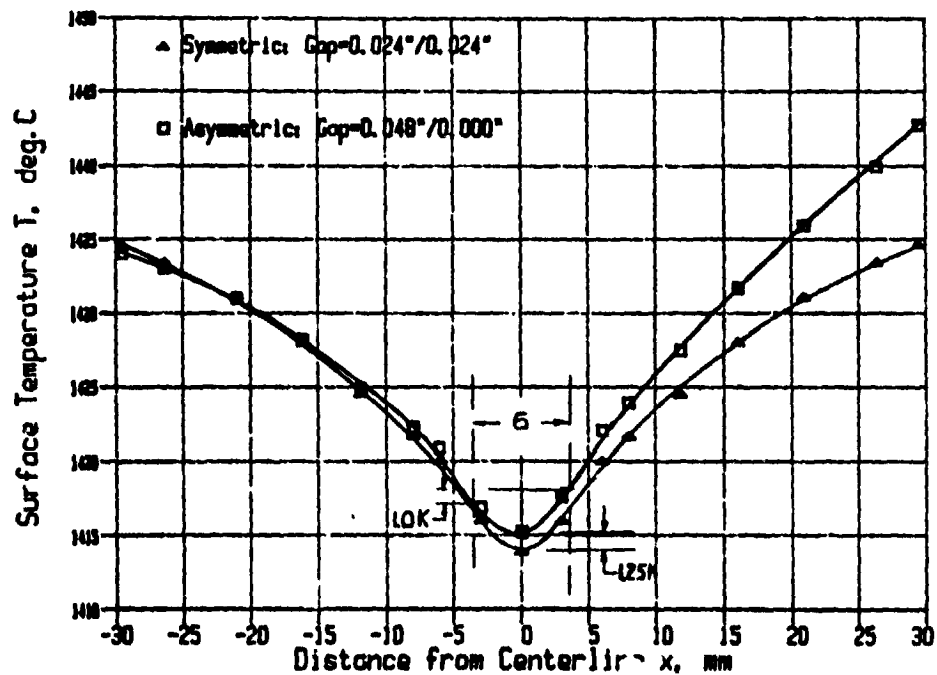
Temperature Distribution in Silicon Web Growth System (Hold Condition)



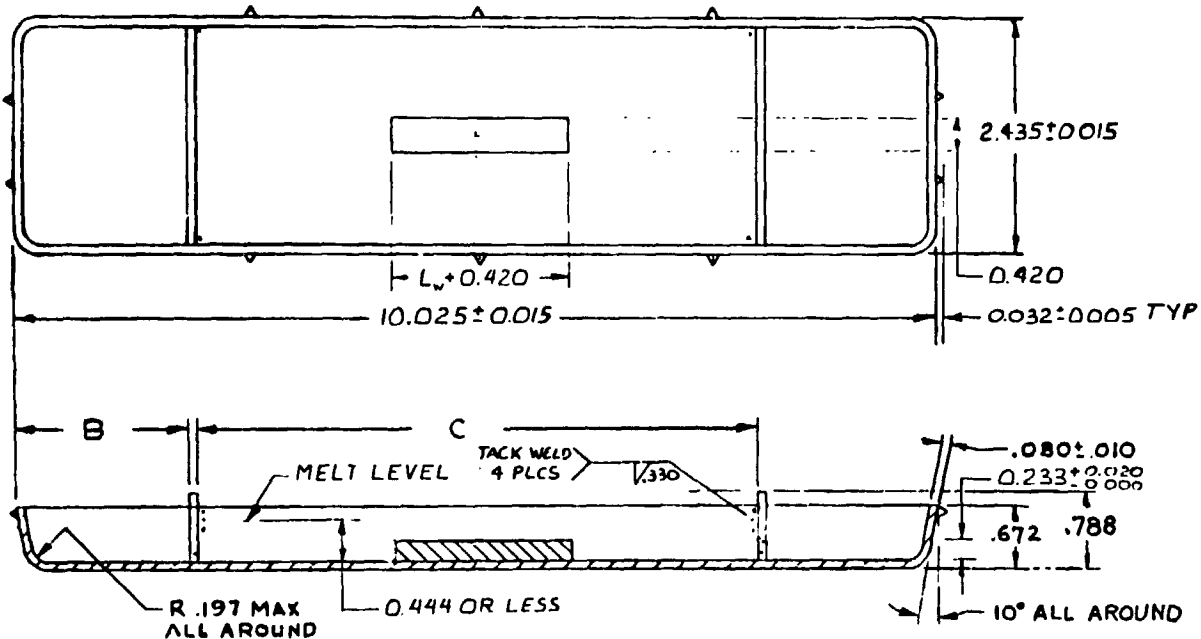
Melt Center Temperature Versus Crucible-Susceptor Gap



Effect of Gaps on Surface Temperature



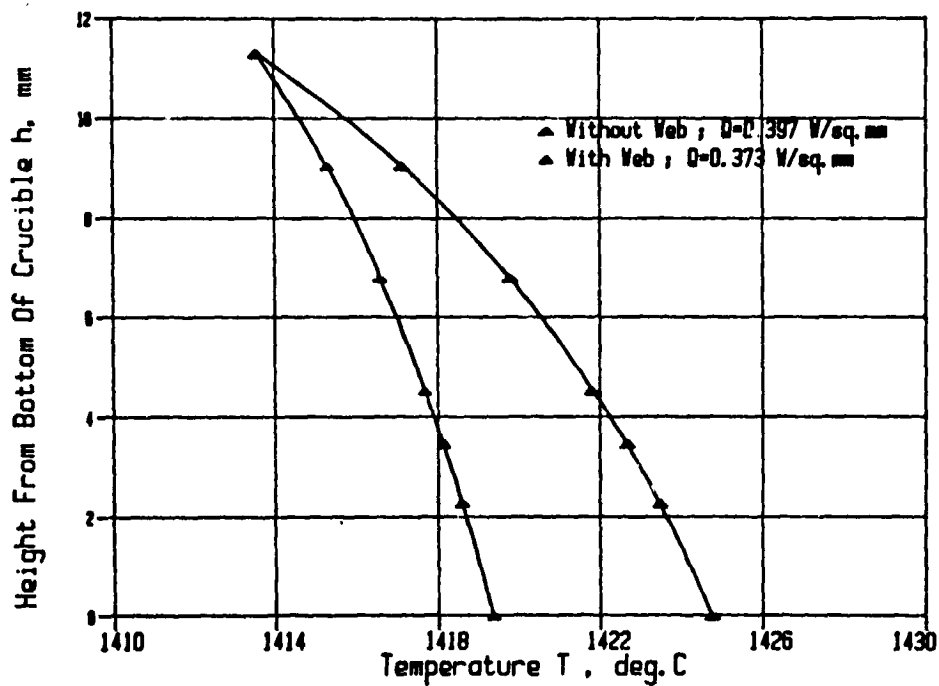
Proposed Crucible Modification
(Spacer Protrusions Added to Crucible)



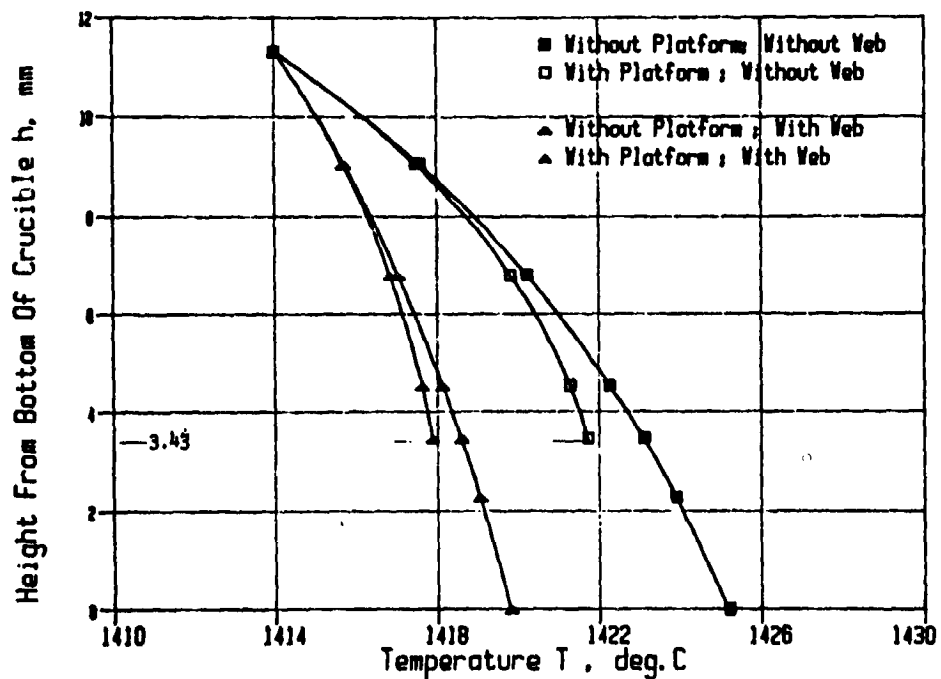
Crucible After 5 Days of Operation
(Spacer Protrusions Machined Into Susceptor)



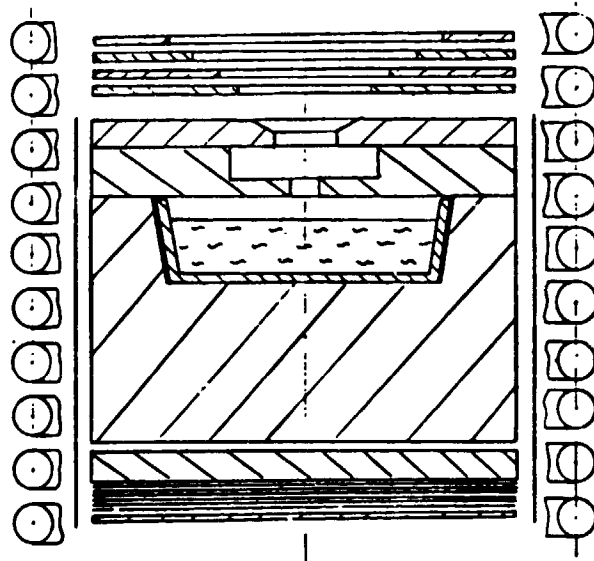
Centerline Temperature Distribution



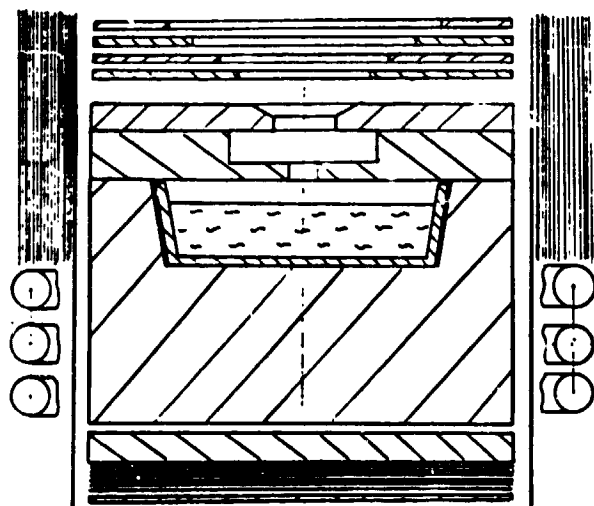
Effect of Platform on Temperature Distribution



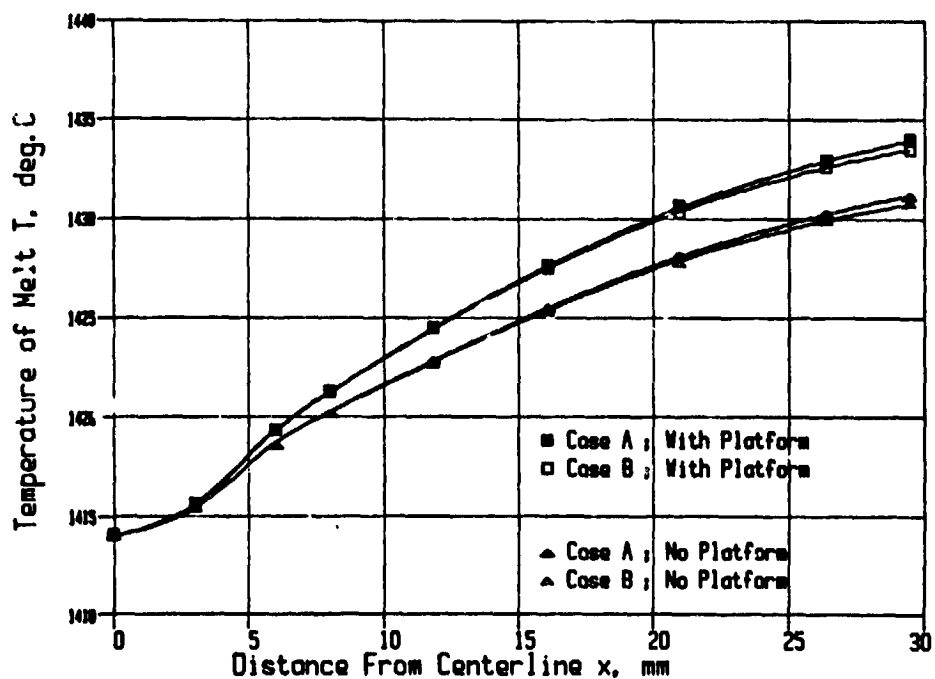
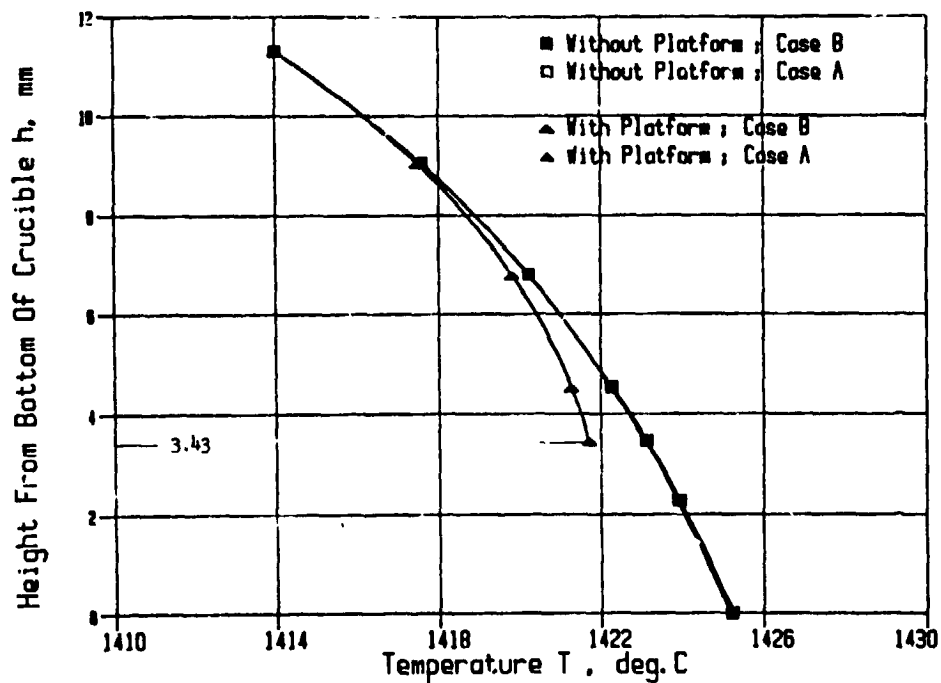
Present Westinghouse Configuration (Case A)



Configuration for Minimum Power Consumption (Case B)

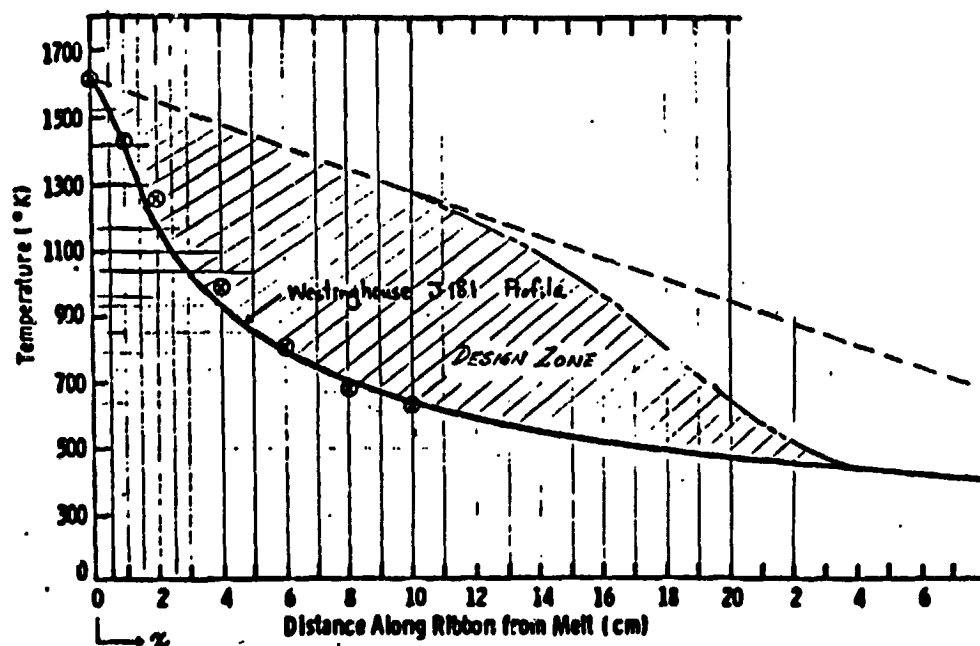


Effect of Power Distribution on Temperature in Melt

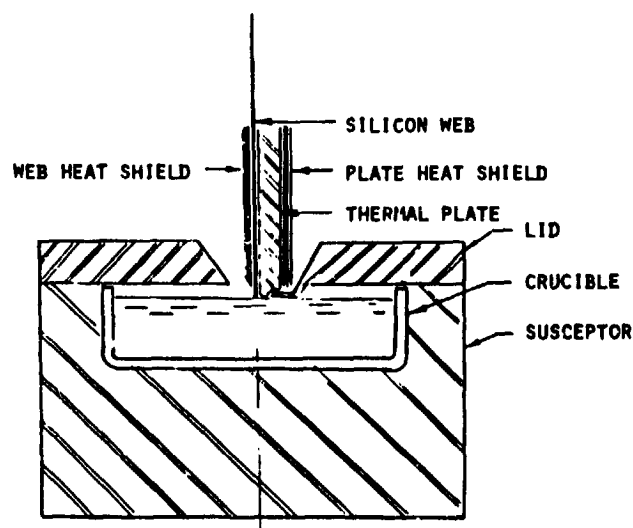


Thermal Stack: Analysis and Design

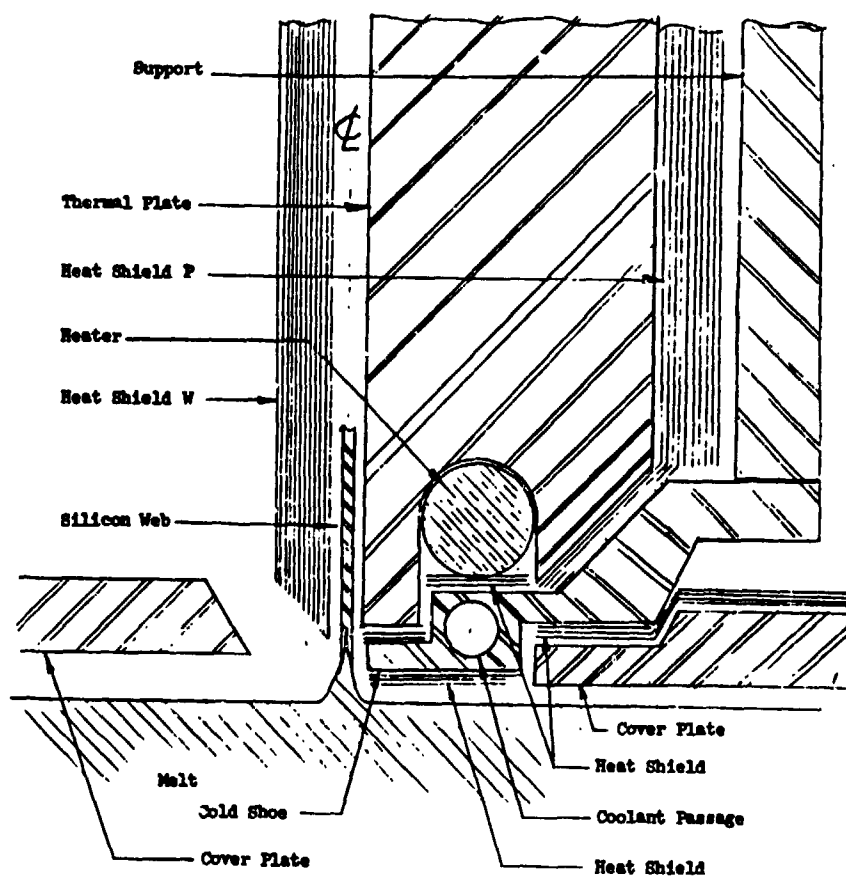
Thermal Web Profile



Proposed Silicon Dendritic Web Growth System (Single Cold Shoe Design)

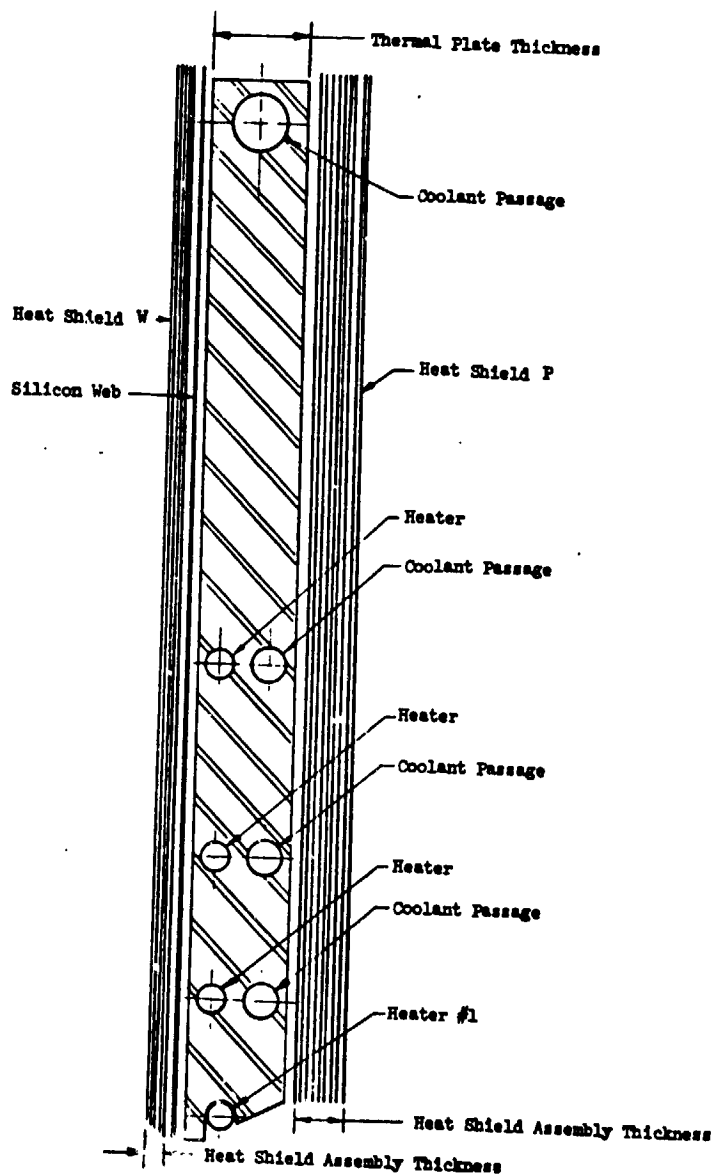


Proposed Single Cold Shoe Design



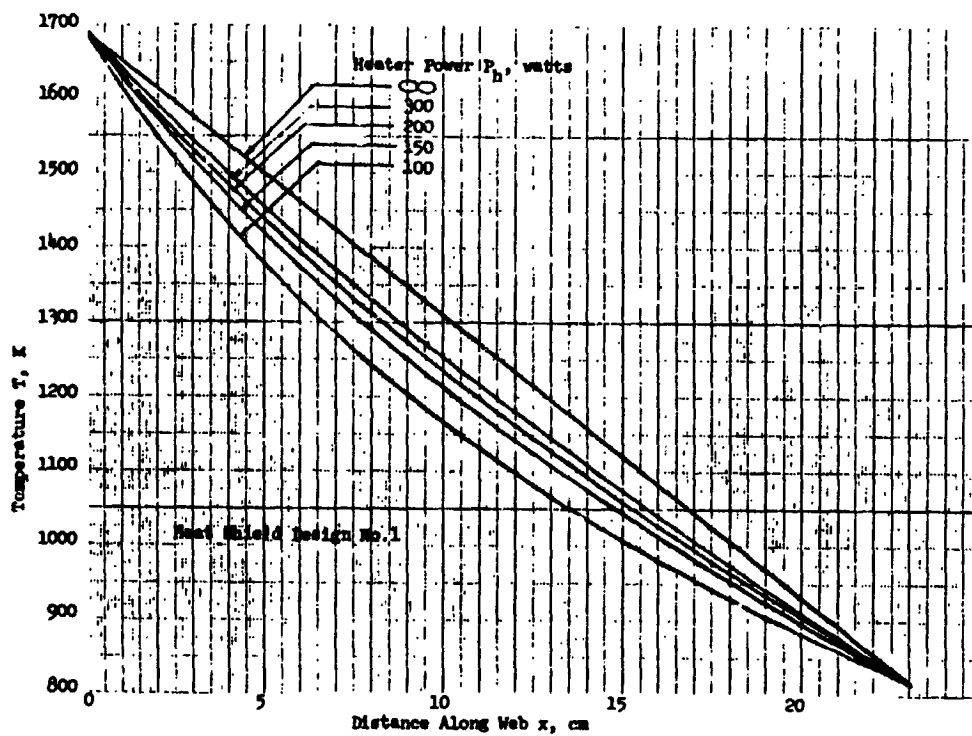
SILICON MATERIAL AND JPL WEB TEAM

Thermal Stack Design (General Layout)

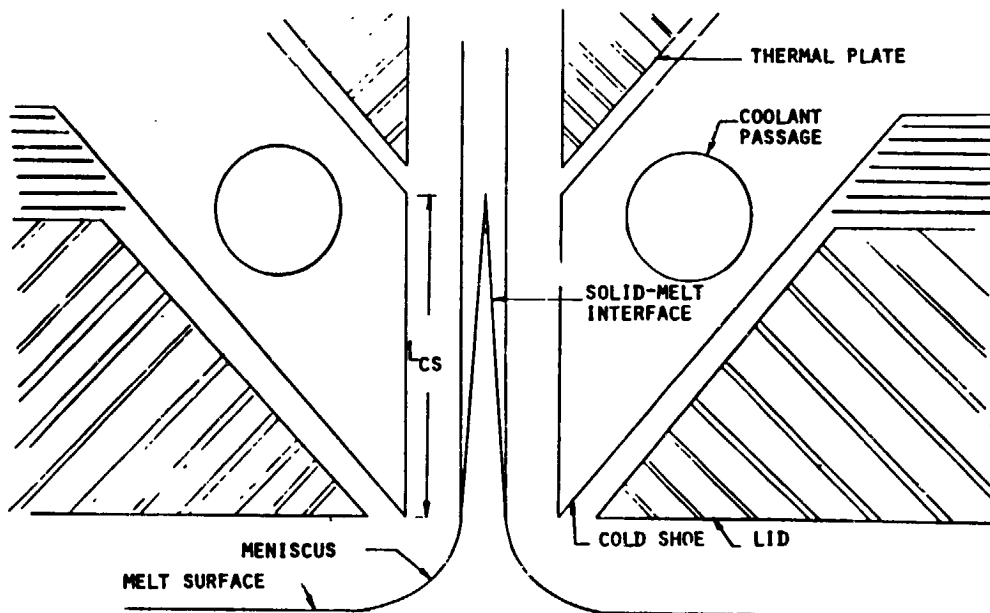


SILICON MATERIAL AND JPL WEB TEAM

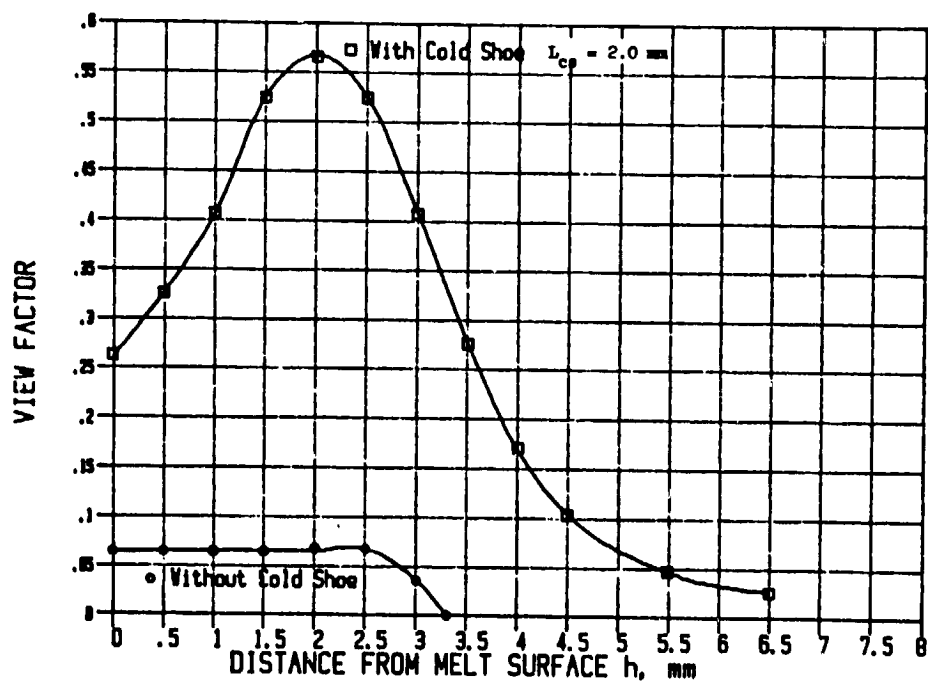
Coid Shoe: Analysis and Design

Temperature Distribution Along the Silicon Web for
Various Thermal Plate Designs

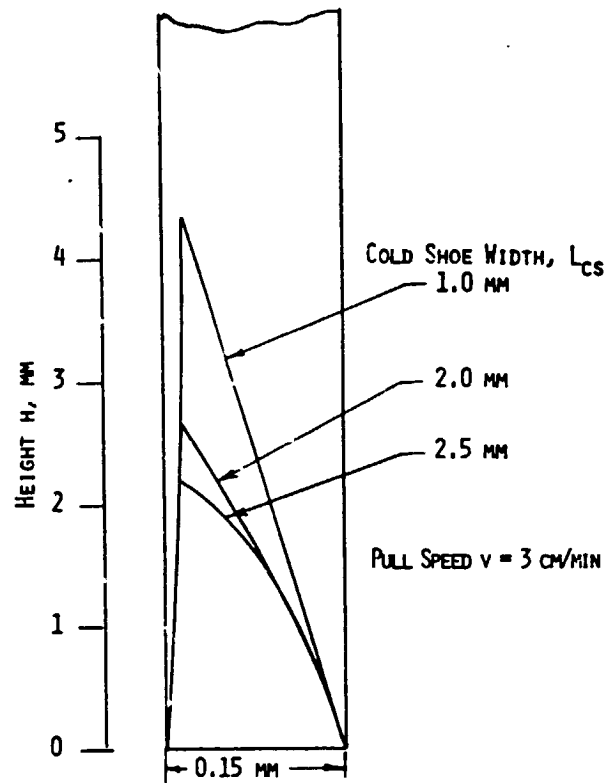
Ideal Cold Shoe Design



View Factor Distribution Along Web Surface



Melt-Solid Interface
(Single Cold Shoe Design)



SILICON MATERIAL AND JPL WEB TEAM

REFERENCES

1. Raymond G. Seidensticker, "Dendritic Web Growth of Silicon," Crystals 8, Springer Verlag, Berlin Heidelberg, 1982 (HC)
2. R. G. Seidensticker and R. H. Hopkins, "Silicon Ribbon Growth by the Dendritic Web Process," Journal of Crystal Growth 50 (1980) 221-235, North-Holland Publishing Company (HC)